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(54) Electronic article surveillance system.

(57) An electronic article surveillance system for microwave frequencies (500 MHz and higher) has low profile (i.e., shallow) transmitter antenna arrays and a low profile receiver antenna array, each array comprising a pair of thin metal patches, spaced apart in the normal direction of travel through a surveillance zone, and a thin metal ground plane behind the patches. The patches and ground plane are in spaced parallel relationship. Each metal patch and the adjacent portion of the ground plane together form a cavity resonator which resonates at a desired transmitter or return signal frequency and thereby form a signal radiating or receiving structure. The patch size, path to ground plane spacing, and spacing between patches are determined by the desired resonant frequency.

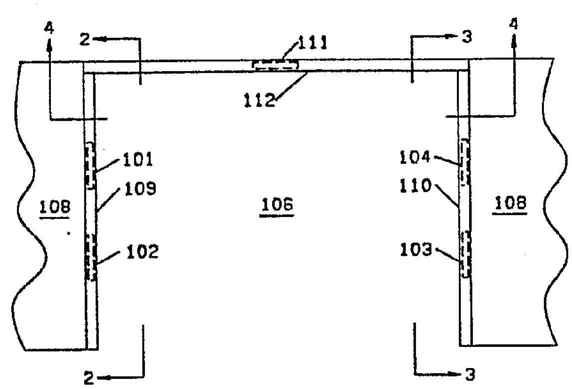

FIG. 1

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ELECTRONIC ARTICLE SURVEILLANCE SYSTEM

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to electronic article surveillance systems and more particularly to electronic article surveillance systems employing microwave transmitter frequencies.

Description of the Prior Art

Systems for deterring or detecting theft of articles, commonly known as electronic article surveillance (or EAS) systems, have come into increasingly widespread use, especially in retail stores. Such systems generally include one or more tags which are attached to articles to be protected against theft, one or more transmitters and associated antennas which radiate signals into a protected area or surveillance zone, and a receiver and associated antenna which will detect the presence of a tag in the surveillance zone and cause an alarm

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to be actuated. The surveillance zone is usually located near an exit from the protected premises. The desired surveillance zone may be an exit doorway, for example.

Electronic article surveillance systems in commercial use may be classified into two groups on the basis of transmitter frequency or frequencies employed. The first group consists of systems employing one or more microwave frequencies. A "microwave frequency" as used herein is a radio frequency higher than 500 megahertz (MHz). The second group consists of systems utilizing lower frequencies. The present system belongs to the first group, i.e., those employing microwave frequencies.

References illustrating microwave EAS systems include U.S. Patent 3,895,368 to Gordon et al., and U.S. Patent 4,063,229 to Welsh et al. The Gordon et al. system includes both a microwave transmitter and a low frequency signal generator. An especially desirable microwave system is the dual frequency system described in the copending commonly assigned application of Harold B. Williams, Serial No. 373,251, filed April 29, 1982 (hereinafter the "Williams application").

Minasy U.S. Patent 3,493,955 is illustrative of systems using frequencies below the microwave range.

Microwave systems constitute a large majority of the electronic article surveillance systems currently in use. An advantage of microwave systems over systems employing lower frequencies is that microwave systems have a longer range than lower frequency systems and can therefore be used to protect wider doorways. This is a major advantage, particularly for protecting stores in shopping malls.

Presently known microwave EAS systems have certain limitations. One is that antennas now used for such systems require appreciable depth. As a consequence, the antennas are generally housed in free standing pedestals of considerable thickness, which are ordinarily placed near an exit doorway of a protected premises. Such installations use valuable floor space and are conspicuous. Unobtrusive installations are not possible.

Another drawback of microwave EAS systems is that all such systems known to date have a problem of "over-ranging" to a greater or lesser extent. "Over-ranging" arises because a transmitter signal or signals are radiated beyond the intended surveillance zone and are picked up, either by tags in the interior of the store or by spurious metal objects, such as strollers or baby carriages either inside or outside the store. The remote tag or spurious metal object may reradiate a signal

back to the receiver, possibly triggering a false alarm. "Over-ranging" continues to be somewhat of a problem despite the use of transmitter antenna arrangements designed to confine the transmitter signals to the desired surveillance zone and despite the use of means within the receiver for discriminating between valid and spurious return signals.

Antennas used in microwave EAS systems include dipole antenna arrays such as those disclosed in the Williams application, and circularly polarized helical antennas such as those disclosed in the copending commonly assigned application of Philip Daniel Fancher, Serial No. 367,715, filed April 12, 1982 (hereinafter the "Fancher application" equivalant to European Application 83102895.6). The transmitter antenna arrays of both the Williams and Fancher applications may include a reflector consisting of a conductive metal panel or mesh grid, and the receiver antennas of the Williams application (like both the transmitter and receiver antennas of Fancher) are circularly polarized. Dipole or turnstile antennas such as those shown in the Williams application radiate or receive signals over a wide angle, so that signals are radiated into or received from both the interior and the exterior of the protected premises as well as the desired surveillance zone. False alarms from tags or spurious metal objects may result, as previously explained. Helical antennas

such as those illustrated in the Fancher application also have a wide beam width (typically about 60°). Although this is narrower than the typical beam width achieved with dipole antennas, it is still wide enough to result in false alarms. In addition, helical antennas require considerable axial length in order to achieve a 60° beam width at a typical EAS transmitter frequency of 915 MHz.

Welsh et al. U.S. Patent 4,063,229, cited supra, also discloses (at column 6, line 54 to column 7, line 4) various forms of antennas and associated accessories (including reflectors) which may be used in microwave EAS systems.

Microstrip antennas have been the subject of a number of patents and other publications in the last decade or so, use of microstrip antennas to date has been confined largely to aircraft, missiles, and other military applications. Patch antennas having an air dielectric have also been developed in recent years, but have not achieved either widespread usage or the prominence in the literature that microstrip antennas have achieved.

U.S. Patent No. 4,366,484 to Weiss et al. describes a temperature compensated radio frequency antenna having two metallic members and a resonant cavity therebetween which is

partially filled with air and partially filled with a dielectric material.

U.S. Patent No. 4,291,312 to Kaloi discloses various forms of dual ground plane microstrip antennas, including arrays having a plurality of radiating elements and a feed network on one side of a dielectric substrate, and a ground planes on both sides of the substrate.

Other U.S. patents illustrating microstrip antennas include the following: 3,803,623 to Charlot; 3,811,128 to Munson; 3,921,177 to Munson, and 3,987,455 to Olyphant.

SUMMARY OF THE INVENTION

According to this invention, a microwave frequency electronic article surveillance system is provided with antenna means comprising an antenna element which includes a metallic patch and a metallic ground plane spaced therefrom. The patch and the ground plane together form a signal radiating or receiving structure. Either the transmitter antenna means, or the receiver antenna means, or (preferably) both, are in accordance with this invention.

To minimize "over-ranging", it is preferred to use a plurality of antenna elements spaced apart along the normal

direction of travel of an article through the surveillance zone.

In preferred embodiments of this invention, the transmitter antenna means includes at least one antenna array for each transmitter frequency, and the receiver antenna means includes at least one antenna array. Each antenna array includes at least two thin metallic patches arranged in spaced apart side-by-side relationship along the normal direction of travel, and a common metallic ground plane behind and spaced from the metallic patches. An array is in effect an assembly of a plurality of antenna elements in which each element comprises a patch and the portion of the common ground plane which is behind the patch. Each antenna element forms a cavity resonator. All elements on an array have the same resonant frequency. The antenna elements are preferably circularly polarized.

An EAS system according to this invention also includes transmitter means for generating at least one microwave signal, tag means comprising at least one tag adapted to be attached to a protected article and operable to receive said at least one microwave signal and to reradiate a return signal, and receiver means for detecting said return signal and actuating an alarm when a tag is present in the surveillance

zone. The transmitter, tag and receiver may all be conventional components of an EAS system.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a front elevational view showing a preferred arrangement of transmitter antenna and receiver antenna arrays in accordance with this invention.

FIG. 2 is a side view, taken along line 2-2 of FIG. 1.

FIG. 3 is a side view, taken along line 3-3 of FIG. 1.

FIG. 4 is a view looking upward, taken along line 4-4 of FIG. 1.

FIG. 5 is a view looking upward, along line 4-4 of FIG. 1, of a modified antenna arrangement according to this invention.

FIG. 6 is a schematic diagram of an electronic article surveillance system which includes the transmitter and receiver antennas of this invention.

FIG. 7 is an isometric view of a tag or passive transponder used in the system shown in FIG. 6.

FIG. 8 is a front elevational view of a transmitter antenna array according to this invention.

FIG. 9 is a front elevational view of a receiver antenna array according to this invention.

FIG. 10 is an enlarged front elevational view of a portion of the array shown in FIG. 8.

FIG. 11 is a vertical sectional view taken along line 11-11 of FIG. 10.

FIG. 12 is a schematic diagram of the feed network for a transmitter antenna array.

FIG. 13 is a schematic diagram of the feed network for a receiver antenna array.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described with particular reference to an electronic article surveillance system having two transmitters which radiate signals on two frequencies in the microwave range. The two frequencies used herein for illustration are 905 MHz and 925 MHz. Such a system is described in detail in the Williams application.

Referring now to FIGS. 1 to 4, the transmitter antenna means of the present invention comprises four low

profile patch type transmitter antenna arrays 101, 102, 103, 104. The arrays are mounted on either side of doorway 106, which is an exit doorway in wall 108 of a protected premises. Two of these arrays, 101 and 102, are concealed in cabinet 109 on one side of doorway 106. The other two arrays, 103 and 104, are concealed in cabinet 110 on the opposite side of doorway 106. Cabinets 109, 110 are non-metallic so as not to interfere with signal propagation.

Each array comprises a plurality of square metal patches, mounted on and spaced from a common rectangular metal ground plane, as will be described in detail with reference to FIGS. 8, 10 and 11. The patches on each array are spaced apart along the normal direction of travel of an article through the surveillance zone, as may be seen in FIGS. 2 and 3. The ground planes of arrays 101, 102 preferably lie in a common vertical plane. Likewise, the ground planes of arrays 103, 104 also preferably lie in a common vertical plane. Both vertical planes are parallel to the normal direction of travel through the surveillance zone.

Arrays 101, 102, 103, 104 are shallow, typically no more than 2 inches (5.1 cm) thick. Consequently, cabinets 109, 110 need not be more than about 3 inches (7.6 cm) thick. Cabinets 109, 110 can therefore be installed unobtrusively at

the sides of doorway 106, and they do not materially decrease the width of the doorway.

Alternatively, the arrays 101, 102, 103, 104 may be placed in free standing pedestals on either side of the doorway. Pedestals are preferred when a conspicuous installation is desired, while the illustrated arrangement affords an unobtrusive installation.

Arrays 101 and 103 (one on each side of doorway 106) radiate one transmitter frequency signal f_1, say 905 MHz. The other two arrays 102 and 104 (one on each side of doorway 106) radiate the other transmitter frequency signal f_2, say 925 MHz. A pair of arrays which radiate the same transmitter frequency signal (e.g., arrays 101 and 103) are preferably placed at different elevations as shown. Both transmitter frequency signals are radiated from both walls to minimize the effect of "shadows" due to the presence of persons or objects within the surveillance zone (since persons and objects act as shields for signals in the microwave range) and thereby to assure that both signals are radiated throughout the surveillance zone.

The receiver antenna means of the present invention comprises a single low profile patch type receiver antenna array 111 which is concealed in cabinet 112 in the ceiling of doorway 106, or suspended close to the doorway. The ground

plane of array 111 lies in a horizontal plane. Cabinet 112 is ordinarily not more than 3 inches thick.

Location of a pair of transmitter antennas on each side of a doorway and a receiver antenna in the ceiling, as described above, is not a novel feature of this invention. Such an arrangement is described in the Fancher application.

The normal direction of travel of a protected article through the surveillance zone (i.e., doorway 106) is from the interior of the protected premises through doorway 106 to the outside. This direction is essentially horizontal. If a protected article having a tag attached thereto passes through doorway 106, the tag will pick up transmitter signals from transmitter antenna arrays 101, 102, 103, 104 and reradiate a return signal to receiver antenna array 111, causing an alarm to sound as will be described later.

FIG. 5 shows an alternative arrangement of antenna arrays. In this arrangement, two transmitter antenna arrays 101, 102, one for each transmitter frequency, and a receiver antenna array 111, are all placed in cabinet 112, which is located in the ceiling above doorway 106 as shown in FIG. 1. The ground planes of all three arrays preferably lie in a common horizontal plane. The patches of all three arrays are

spaced apart along the normal direction of travel of an article through the surveillance zone.

FIG. 6 illustrates a preferred electronic article surveillance system in which the antennas of the present invention may be utilized. This system may be like that of the Williams application except for antenna structures and placement.

Referring to FIG. 6, the present system has transmitter means comprising transmitters 121, 122 which generate microwave signals. The frequencies of the signals generated by transmitters 121, 122 are preferably close together, that is, they preferably differ from each other by no more than about three percent. For purposes of illustration herein, transmitters 121, 122 generate signals having frequencies of 905 MHz and 925 MHz, respectively. One of these signals, say the 925 MHz signal, may be modulated by a low frequency audio tone (2 kilohertz, for example). The other signal is preferably an unmodulated continuous wave signal.

The signal generated by transmitters 121, 122 (also designated as TR-1 and TR-2, respectively) are fed through cables 123, 124 to antenna arrays 101, 102, and through cables 125, 126 to antenna arrays 103, 104. The cables may be conventional low loss coaxial cables. Antenna arrays 101, 102

are located on one side of the surveillance zone (i.e., doorway 106) and antenna arrays 103, 104 are located on the opposite side of the surveillance zone. The signals fed to antenna arrays 101, 102 (which are on the side of doorway 106 more remote from the transmitters 121, 122) may be amplified by linear amplifiers 127, 128. The linear amplifiers 127, 128 compensate for the losses in cables 123, 124 and include filtering to eliminate noise and reduce undesired intermodulation products.

Transmitters 121, 122 and amplifiers 127, 128 have appropriate power supplies (typically providing a low D.C. voltage, e.g., 18 volts derived conventionally from 110 volt or 220 volt AC power lines) not shown.

Transmitter antenna arrays 101, 102, 103, 104 (which collectively constitute transmitter antenna means) radiate their respective microwave signals into the surveillance zone, i.e., doorway 106.

The system of this invention also includes one or more tags 130, which may be attached to protected articles. A tag 130, when in the surveillance zone, receives microwave signals from antennas 101, 102, 103 and 104 and reradiates one or more return signals in response thereto. The return signals

are received by receiver antenna array 111. The preferred tag is a passive transponder.

FIG. 7 illustrates the preferred tag 130 in detail. Tag 130 comprises a flat metal antenna loop 132 with a gap on one side, and a non-linear impedance element 134 which may be a semiconductor diode, supported on or embedded in a non-conductive (e.g., plastic) substrate 136. Antenna loop 132 provides a folded dipole configuration. The overall length and shape of antenna loop 132 are preferably chosen to make it resonant at a mean center frequency, which is the arithmetic mean between the two microwave frequencies generated by transmitters 121, 122. The mean center frequency in the illustrated embodiment is 915 MHz (transmitter frequencies in the illustrated embodiment are 905 MHz and 925 MHz as previously noted). While the details of tag 130 do not form part of the present invention and are essentially the same as the details of the tag or transponder of the Williams application, they have been repeated here for convenience.

Because of its non-linear nature, tag 130 responds to the transmitter signals (905 MHz and 925 MHz in the illustrated embodiment) by reradiating a small return signal at the sum frequency signal of 1830 MHz, in addition to other return signals (including the second harmonic frequencies of 1810 MHz

and 1850 MHz) of lesser amplitude. The sum frequency signal (and other signals) reradiated by tag 130 will include any modulation which is present in either of the transmitter signals.

Returning now to FIG. 6, receiver 140 is coupled through cable 142 to receiver antenna array 111. Receiver 140 is also coupled to alarm 144.

One may use compact transmitters 121, 122 located inside cabinets 109, 110, and a compact receiver 140 located inside cabinet 112, instead of remotely located transmitters and receiver as shown in FIG. 6, if desired. (In the embodiment of FIG. 5, compact transmitters and a compact receiver may be located in cabinet 112.) The alarm 144 is usually placed at a location remote from the surveillance zone (it may be placed in the store offices, for example).

The preferred receiver 140 is a narrowband receiver like the receiver described in the copending Williams application. Such a receiver responds to a sum frequency return signal (1830 MHz) to the exclusion of the transmitter signals (905 and 925 MHz) and their harmonics. In other words, receiver 140 excludes the adjacent second harmonics (1810 and 1850 MHz) as well as higher harmonics. When a sum frequency signal (1830 MHz) exceeding a predetermined threshold amplitude

is received by receiver 140, the receiver responds by admitting the signal to a demodulator or detector circuit. The threshold amplitude is a safeguard against false alarms due to spurious signals received from outside the surveillance zone. When one of the two transmitter signals is modulated, as is preferred, the return signal is also modulated. System reliability and sensitivity are further enhanced in this case by having the receiver 140 supply an output signal to alarm 144 only when the frequency of the modulating tone signal detected matches the frequency being transmitted as modulated from the transmitter for a predetermined fixed interval which is indicative of the actual presence of a tag 130 in the surveillance zone. Further details of the preferred receiver are given in the Williams application.

The preferred transmitter antennas will now be described with reference to FIGS. 8, 10 and 11. Since all four transmitter antenna arrays 101, 102, 103, 104 are structurally alike except for slight differences in size (arrays 102, 104 are slightly smaller than arrays 101, 103 because they radiate a signal of slightly higher frequency), only array 101 will be described in detail.

Referring to FIG. 8, transmitter antenna array 101 comprises a plurality of horizontally spaced thin flat square

sheet metal (e.g., aluminum or mild steel) patches (two patches 151, 152 are shown) supported on, spaced from and parallel to a thin rectangular sheet metal (e.g., aluminium) ground plane 154. Air occupies the space between patches 151, 152 and ground plane 154. The patches 151, 152 are arranged in spaced relationship along the longitudinal axis of the ground plane 154.

Patches 151, 152 are approximately but not exactly one-half wavelength on each side. Good results have been obtained with patches 0.46 wavelength on each side.

A preferred receiver antenna array 111 will now be described with reference to FIG. 9. Receiver antenna array 111 has a plurality of horizontally spaced thin square metal (e.g., brass) patches 181, 182, 183, 184, supported on, spaced from and parallel to a thin rectangular sheet metal (e.g., aluminum) ground plane 186. The patches 181, 182, 183, 184 are arranged in spaced relationship along the longitudinal axis of ground plane 186. Receiver antenna array 111 is structurally similar to the transmitter antenna arrays, except that the receiver antenna patches 181, 182, 183, 184 are about one-half the size of patches 151, 152 in the transmitter antenna arrays 101, 102, 103, 104 in order to achieve the desired resonant frequency. Likewise the spacing between patches is also about half as

great as the spacing between patches of the transmitter antenna arrays. The ground planes 154, 186 of the transmitter and receiver antenna arrays 101, 111 respectively are typically the same size. It is therefore possible to fit four receiver antenna patches into the same space that is required for two transmitter antenna patches.

The structure of a preferred transmitter antenna element will now be described in further detail with reference to FIGS. 10 and 11. Referring now to FIGS. 10 and 11, a conductive center post 155 extends from each patch 151, 152 to the ground plane 154, providing a conductive path therebetween. Only patch 151 is shown in FIGS. 10 and 11, but patches 151, 152 and the means used to support both patches 151, 152 from ground plane 154 are structurally the same. Center post 155 may comprise an externally threaded screw 155a surrounded by a bushing 155b. Four corner posts or spacers 156 also extend from patches 151, 152 to ground plane 154. The corner posts 156 may be made of glass filled phenolic plastic or other suitable dielectric material. The bushing 155b and corner posts 156 maintain the desired spacing between the patch and the ground plane. For patches radiating signals of 905 MHz and 925 MHz, the preferred spacing of patches 151, 152 from ground plane 154 is typically about 0.23 inch. The spacing may be

varied, but any such variations affect both resonant frequency and band width, as is known in the antenna art. If all other parameters (e.g., patch size and corner post size and material) remain fixed, the spacing between patches and ground plane must be held within tolerance limits of about 0.001 inch for reproducible performance, since very slight changes in spacing without compensating changes in other parameters result in significant changes in resonant frequency. The non-conductive corner posts are in regions of high electric field and therefore influence the resonance of the cavity formed by a patch and the ground plane. Neither the materials, nor the form nor the dimensions of the corner posts can be changed without affecting the resonance of the antenna, or, if any such change is made compensating changes must be made in the other parameters.

Each patch 151, 152 has a pair of holes 157, 158, which constitute feed points for a transmitter signal, as seen best in FIG. 11. Transmitter signals may be fed to these feed points via coaxial conductors 159, which may be conventional. Each coaxial connector 159 has a conductive core 159a, which terminates in patch 151 (or 152) at a feed point 157 or 158 and which passes through and is insulated from ground plane 154 (holes in the ground plane are provided for this purpose).

Each connector 159 also has a metal shield which is coaxial with core 159a and which terminates in ground plane 154. Feed points 157, 158 are equidistant from the center post 155 along the vertical and horizontal axes, respectively, of the patch. The spacing from the center is determined to make the input impedance of the cavity match that of the cable. Two additional holes 157a, 158a, at the same distance from center post 155 as holes 157, 158 but in opposite directions, may be provided if desired. By providing four holes, only two of which are used as feed points, one may rotate the patch at the time of assembles to obtain the best possible impedance matching.

Patches 151, 152 are elliptically or circularly (preferably circularly) polarized in order to minimize the effect of tag orientation. This is accomplished by locating the feed points 157, 158 as just explained and by feeding the signals 90° out of phase, according to techniques known in the antenna art.

Each patch 151 or 152 and the portion of the ground plane 154 behind it acts as a leaky cavity resonator, i.e., a cavity resonator with so-called magnetic walls, which is tuned to the transmitter frequency which the patch radiates. All patches on an array are tuned to the same resonant frequency.

Patches 151, 152 are roughly one-half wavelength (actually about 0.45 wavelength) on each side. The thickness of patches 151, 152 is not critical. Usually thin patches, typically about 1/32 inch (about 0.8 mm), will be used.

The primary direction of radiation from each patch (i.e., the dominant lobe) is along an axis perpendicular to the patch. In the embodiment shown in FIGS. 1 to 4 these primary axes of radiation are horizontal, i.e., across doorway 106 from one side to the other. In the embodiment shown in FIG. 5, the primary direction of radiation is vertically downward into doorway 106. Side lobes may also be radiated. Signal amplitude is greatest along the primary axis and in general decreases as the angle from the primary axis increases. Ground plane 154 prevents back radiation (i.e., radiation away from the surveillance zone) except for a small amount which goes around the edges. This is important for stores where tagged goods are near the doors.

The patches on an array, i.e., patches 151, 152 in the embodiment shown, are spaced apart in the normal direction of travel of a tag through the surveillance zone. Since the usual direction of travel of a tag is horizontal, the patches on an array are spaced apart horizontally. By providing a plurality of appropriately spaced patches on each array, it is

possible to minimize radiation of transmitter signals outside the surveillance zone. The signals radiated sideways (and therefore to locations outside the surveillance zone) cancel each other out or at least minimize each other, so that very weak signals, and in some directions virtually no signals, are received outside the surveillance zone. On the other hand, the patches do radiate vertically throughout the entire height of doorway 106, since the patches are so placed that no interference in the vertical direction takes place. A preferred spacing between patches 151, 152 is about three-quarters of a wavelength center to center.

A two-patch antenna array 101 as shown, in which the patch-to-patch spacing is three-quarters of a wavelength, has a half power (-3db) beam width of 40° in the longitudinal direction of the array with minimal side lobes. The half power beam width in the transverse direction is about 60°. By comparison, a single patch antenna element has a half power beam width of about 60° measured in either direction. A helical antenna of known form also has a half power beam width of about 60°. Half power beam width is a useful measurement for comparing the directionality of different antennas, although it does not ordinarily coincide with the actual width over which a signal is effectively radiated or received.

More than two patches can be used when space permits. Use of more patches decreases the extent of overranging beyond the doorway (or beyond the space between the pedestals when they are used). Use of two patches as illustrated is based on the assumption that the depth of doorway 106 (i.e., the dimension in the direction of travel of an article) is two feet.

Each of the arrays 101, 102, 103, 104 may be replaced by an antenna element having a single patch 151 and a ground plane 154, where the passageway to be protected is narrow. Such would be the case, for example, at an escalator landing or in a small shop situated on a street and having a narrow doorway. Such installation may also be used where necessitated by space limitations, as for example, when doorway 106 is in a wall substantially less than two feet thick. Use of a single antenna element in place of an array is not preferred for wider doorways. When a single antenna element (or a single element on each side of doorway 106) is used for each transmitter frequency, the signal of that frequency is radiated outside the surveillance zone due to the broader pattern from that element, without the extinction or attenuation which is achieved with a properly designed array.

To recapitulate, the resonant frequency of a cavity formed by a patch and the adjacent ground plane is influenced by the patch size, the spacing between the patch and the ground plane, and the size and materials of the dielectric spacers (i.e., the corner posts 156) between the patch and the ground plane. Experimental adaptation of a design is usually necessary for an exact determination of suitable dimensions. Resonant frequency is sensitive to small changes in patch size, and is extremely sensitive to small differences in spacing between the patch and the ground plane. Furthermore, patches which deviate from flatness may show mismatch between the electrical characteristics as measured at the two feed ports, and fail to give satisfactory circular polarization. The thicknesses of a patch and the ground plane are not critical initially, but once the design is fixed, they cannot be arbitrarily changed. For convenience they are made of thin sheet metal. The total thickness of an array is typically less than one-half inch (1.3 cm), although the feed network (to be described with reference to FIG. 12), which is usually mounted behind ground plane 154, may take up more space.

Referring again to FIG. 9, patches 181, 182, 183, 184, and the portions of the ground plane 186 behind the patches, act as cavity resonators tuned to a frequency

reradiated by tag 130. When the transmitter frequencies are 905 and 925 MHz, one of the reradiated frequencies is 1830 MHz. Receiver antenna array 111 is advantageously tuned to this frequency.

Patches 181, 182, 183, 184 are structurally similar to patches 151, 152, but are preferably circularly polarized in the opposite direction from the direction of polarization of the transmitter patches. If the transmitter patches are polarized to the right, the receiver patches are polarized to the left, and vice versa. Thus, each patch 181, 182, 183, 184 includes a conductive center post 187, non-conductive corner posts 188 at each corner, and holes or feed points 189a, 190a for coaxial conductors 189, 190, respectively. The feed points 189a, 190a are equidistant from center post 187 along the two principal axes (which are at right angles to each other) of the patch. Two extra holes (analogous to holes 157a, 158a in the transmitter antenna arrays) may be provided as alternate feed point locations if desired.

The receiver antenna array 111 of this invention is highly selective to a predetermined frequency. In addition, because the receiver antenna array typically has four patches instead of two as in a transmitter antenna array of the same size, the receiver antenna "pickup" or signal reception zone is

more closely confined to doorway 106 (or other desired surveillance area) than is the case with the transmitter antenna arrays. A four-patch receiver antenna array as shown herein has a half power beam width angle of about 18°, compared to about 40° in the two-patch transmitter antenna array shown. This makes it possible to place tagged merchandise close to the doorway 106 inside the store if desired; even if the tag picks up transmitter signals from the transmitter antenna arrays 101, 102, 103, 104, the return signal from the tag will not necessarily be picked up by the receiver antenna array 111. Also, a receiver antenna array 111 will not pick up return signals from tags which are close to the doorway on the exterior side thereof (for example, tags similar to tag 130 which were affixed to an article by another store in the same shopping mall and not removed from article before it was taken out of store).

The receiver antenna array may have any desired number of patches, from two on up, instead of the four patches shown in FIGS. 1 and 8. However, use of fewer patches results in a broader signal pickup zone.

FIG. 12 shows schematically the feed network for supplying a transmitter signal to a transmitter antenna array. Transmitter antenna array 101 has been chosen for purposes of

illustration. The feed networks for all transmitter antenna arrays are the same.

The transmitter signal from transmitter 121, after amplification in amplifier 127, passes through the feed network shown in FIG. 12 to array 101. This feed network includes a first stage power divider 170, a pair of output signal lines 171, 172 connected to divider 170, and a pair of second stage power dividers 173, 174 connected to lines 171, 172 respectively. Lines 171, 172 are of equal length. Coaxial conductors 175, 176, 177, 178 connect the output sides of dividers 173, 174 with connectors 159 (see FIG. 11) on patches 151, 152 and their respective ground planes 154. Conductors 176 and 178 are one-quarter wavelength longer than conductors 175 and 177 so that patches 151, 152 are circularly polarized.

The network for conveying reradiated signals from receiver antenna array 111 to receiver 140 will now be described with reference to FIG. 13. Referring to FIG. 13, reradiated signals picked up by patches 181, 182, 183, 184 are fed to combiners 191, 192, 193, 194 respectively. The output signals from combiners 191, 192 are fed to combiner 195, and the output signals from combiners 193, 194 are fed to combiner 196. The output signals from combiners 195, 196 are fed to

combiner 198. The output signal from combiner 198 is fed via cable 142 to receiver 140.

Both the transmitter and receiver antenna feed networks are preferably compact and are located inside cabinets 109, 110, or 112 behind the ground planes 154 or 186 of the antenna arrays which they serve.

Transmitter and receiver antenna arrays as shown and described herein, and having the characteristics given in Table 1 below, have been found to perform satisfactorily when operated with feed networks and interconnecting cables having 50 ohm characteristics impedances.

Table 1

	Transmitter arrays		Receiver array
Resonant frequency, MHz	905	925	1830
Patch size (length of each side), inch (cm)	5.955 (15.2)	5.810 (14.8)	2.880 (7.3)
Distance from feed point to center of patch, inch (cm)	1.075 (2.73)	1.075 (2.73)	0.538 (1.37)
Spacing from patches to ground plane, inch (cm)	0.230 (0.58)	0.230 (0.58)	0.113 (0.29)
Spacing between adjacent patches, center-to-center	9.67 (24.6)	9.67 (24.6)	4.84 (12.3)
Diameter of corner posts, inch (cm)	0.25 (0.64)	0.25 (0.64)	0.25 (0.64)

Operation

When a purchaser of a protected article pays for it in the usual way, he or she will do so before reaching the surveillance zone, and the tag will be removed at the time of payment. The purchaser then passes freely through the surveillance zone and no alarm is sounded.

If a shoplifter attempts to take a protected article out of a store (or other protected premises) without having the tag 130 removed, he must pass through the surveillance zone in passing through doorway 106. As he does so, tag 130 picks up transmitter signals radiated from transmitter antenna arrays 101, 102, 103, 104, and reradiates a return signal (typically a sum frequency signal in the dual frequency system illustrated). This return signal is picked up by receiver antenna 111 and conveyed to receiver 140. Receiver 140 will recognize the return signal as valid and cause alarm 144 to be actuated.

Modifications

The present invention may be utilized generally with EAS systems having at least one transmitter frequency above 500

MHz. Although the present invention may be used in EAS systems having transmitter frequencies lower than 500 MHz, such use is usually impractical because of the large size of transmitter antenna arrays required. While the dual frequency system of the Williams application is preferred and has been used for purposes of illustration, the antennas described herein could be used with other microwave EAS systems, such as those described in Gordon et al. U.S. Patent 3,895,368 or Welsh et al. U.S. Patent 4,063,229, both cited supra. However, the antenna system of the present invention is more effective in preventing unwanted spread of the surveillance zone in systems employing two microwave frequencies (such as the Williams system) than it is in systems utilizing a single microwave frequency (such as those described in Gordon et al. or Welsh et al.). This is because the strength of a signal reradiated by a tag 130 is proportional to the product of the amplitudes of the transmitter signals which the tag receives in the case of a dual frequency system. Transmitter signal amplitude diminishes as one goes outside the doorway region, and the product of the two transmitter signals diminishes even more rapidly. When the EAS system chosen uses both microwave and low frequencies, as is the case in the system of the Gordon et al. patent, the present antenna arrays are used only for the microwave signal.

Circular or other shaped patches may be used instead of square patches in both the transmitter and receiver antenna arrays.

Any desired arrangement of transmitter and receiver antenna arrays may be used. For example, one may place both transmitter and receiver antenna arrays on opposite sides of the surveillance zone, either in cabinets 109, 110 or in pedestals, and dispense with the overhead or ceiling receiver antenna array. (The Williams application shows such an arrangement). All arrays should be mounted so that the patches in each array are spaced apart in the direction of travel through the surveillance zone. Location of all transmitter antenna arrays on only one side of the surveillance zone is not preferred, because both the human body and objects in the surveillance zone produce "shadows" which would permit a tag to escape detection.

Instead of one or more transmitter antenna arrays, one may provide two or more separate transmitter antenna elements, each of which includes a patch and a ground plane, for each transmitter frequency. The elements in such instance are arranged in side-by-side relationship in the normal direction of travel. Similarly, two or more receiver antenna elements may in principle replace a receiver antenna array.

However, in practice the need to have accurate phase relationships maintained between patches, and patch spacing matched to the wavelength of signals in order to minimize "overranging", makes it much better to use prefabricated arrays, as shown and described herein.

General

Antenna arrays according to this invention with their feed networks can be made less than two inches thick. (The antenna arrays themselves can be made less than one-half inch thick). Installation of the system therefore need not significantly decrease the effective width of the passageway to be protected. The system can be installed unobtrusively behind a doorway jamb as illustrated or it can be installed conspicuously in free standing pedestals, provided in either case that the intervening non-conducting material of construction of the doorway or pedestal is not water-absorbing and is not so close that its dielectric properties materially affect the operation of the antennas. If a concealed doorway installation is chosen, the space requirements for the antennas are minimal.

Receiver antenna arrays according to this invention can be placed in high doorways or ceilings without losing their effectiveness and without undue spread of the signal reception zone beyond the doorway. (The zones of effective signal reception in the direction of travel may be approximated by planes which extend from the sides of the receiver antenna array. These planes make only a small angle with the vertical in the case of overhead receiver antenna arrays).

The surveillance zone can be confined more closely to the space desired, i.e., the space within or close to the exit passageway, than is the case with previous EAS antenna systems. Transmitter antenna arrays of this invention can be readily constructed to give chosen beam patterns which will control the spread of the surveillance zone.

Similarly, the receiver antenna array effectively picks up signals only from the surveillance zone. The received strength of signals from outside the surveillance zone is so low that the alarm will not sound, due to the arrangement of antenna patches which nullifies or greatly attenuates signals from outside the surveillance zone.

The receiver antenna is highly selective for a desired return signal frequency. The receiver antenna thus

enhances the sensitivity of the receiver itself in discriminating between valid and spurious return signals.

One may use the antenna of this invention only for the transmitter antenna(s) or only for the receiver antenna, with another type of antenna being used for the other, if desired. Such installation, for example, may include an overhead receiver antenna array according to this invention with helical transmitter antennas on the sides of the surveillance zone. Of course, some of the advantages of this invention are lost in such case. For example, if one uses a receiver antenna of this invention with a prior art transmitter antenna, one loses some control over spread of the surveillance zone which the present transmitter antenna affords. If one uses transmitter antennas according to this invention with prior art receiver antennas, one confines authentic transmitter signals to the surveillance zone but does not screen out spurious return signals from outside the surveillance zone as effectively as one does when using a receiver antenna according to this invention. It is especially important to use receiver antennas according to this invention, since the improvement in reducing "overranging" is more marked in the case of receiver antennas than is the case with transmitter antennas, as already indicated.

A two-patch transmitter antenna array according to the present invention when used for radiating both transmitter frequency signals of a dual microwave frequency system such as that described in the Williams application, cuts the amount of "overranging" of each transmitter signal by approximately half as compared to a helical antenna arrangement. The antenna means of the present invention, when used for receiving a single return signal frequency, cuts the amount of "overranging" in the zone of effective reception by approximately three quarters. (Comparisons are based on comparative half power beam width angles). When the antenna arrays according to this invention are used for both the transmitter signals and the receiver, the amount of "overranging" is cut even more than when such antenna arrays are used for either transmitter or receiver antennas alone. The present invention therefore provides an effective means for diminishing the extent of "overranging", which has been a major source of false alarms in previous EAS systems.

While this invention has been described with reference to specific embodiments and possible modifications it will be apparent that other modifications can be made by those skilled in the art without departing from the present invention.

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CLAIMS

1. An electronic article surveillance system comprising transmitter means for generating at least one microwave signal, transmitter antenna means for radiating said at least one microwave signal into a surveillance zone, tag means comprising at least one tag adapted to be attached to a protected article and operable to receive said at least one microwave signal and to reradiate a return signal, receiver antenna means for receiving said return signal, and receiver means for detecting said return signal and actuating an alarm when a tag is present in said surveillance zone, characterized in that at least one of said antenna means comprises an antenna element which includes a metallic patch and a metallic ground plane parallel thereto and spaced therefrom, said patch and said ground plane together forming a signal radiating or receiving structure.

2. An electronic article surveillance system according to claim 1, characterized in that said transmitter antenna means comprises an antenna element which includes a metallic patch and a metallic ground plane spaced therefrom, said patch and said ground plane together forming a transmitter signal radiating structure.

3. An electronic article surveillance system according to claim 1 or 2, characterized in that said receiver antenna means comprises an antenna element which includes a metallic patch and a metallic ground plane spaced therefrom, said patch and said ground plane together forming a return signal receiving structure.

4. An electronic article surveillance system according to any one of the preceding claims, characterized in that said metallic patch is a square patch.

5. An electronic article surveillance system according to claim 1, characterized in that said antenna element is circularly polarized.

6. An electronic article surveillance system according to claim 1, characterized in that at least one of said antenna means includes one or more antenna arrays, each

antenna array including a plurality of metallic patches spaced apart along the normal direction of travel through the surveillance zone and a metallic ground plane spaced from said patches, each of the patches and the portion of the ground plane behind said patch forming a cavity resonator, each array being tuned to a single resonant frequency.

7. An electronic article surveillance system according to claim 6, in which said antenna means includes transmitter antenna means.

8. An electronic article surveillance system according to claim 7, in which said transmitter antenna means includes at least two antenna arrays tuned to different resonant frequencies.

9. An electronic article surveillance system according to claim 6, 7 or 8, in which said antenna means includes receiver antenna means.

10. An electronic article surveillance system according to claim 1, in which there is an air space between said patch and said ground plane.

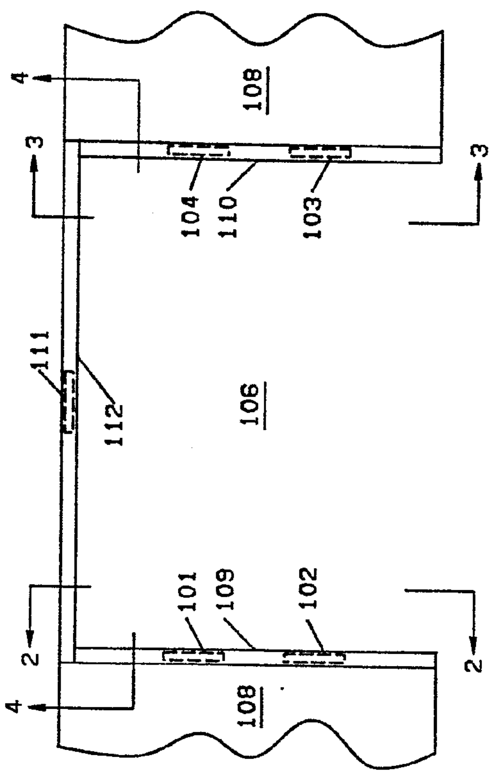

FIG. 1

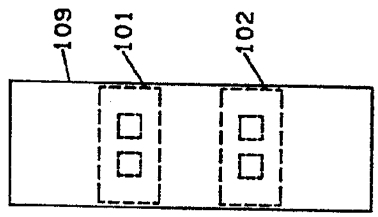

FIG. 2

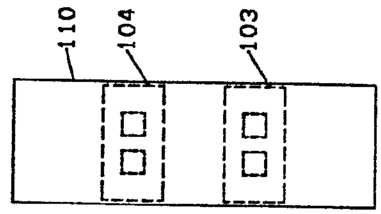

FIG. 3

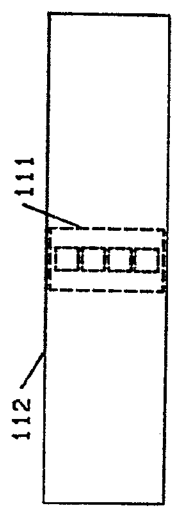

FIG. 4

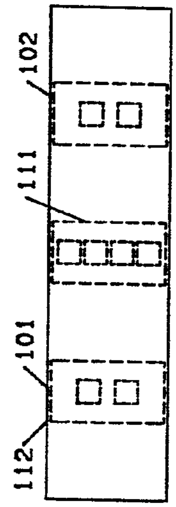

FIG. 5

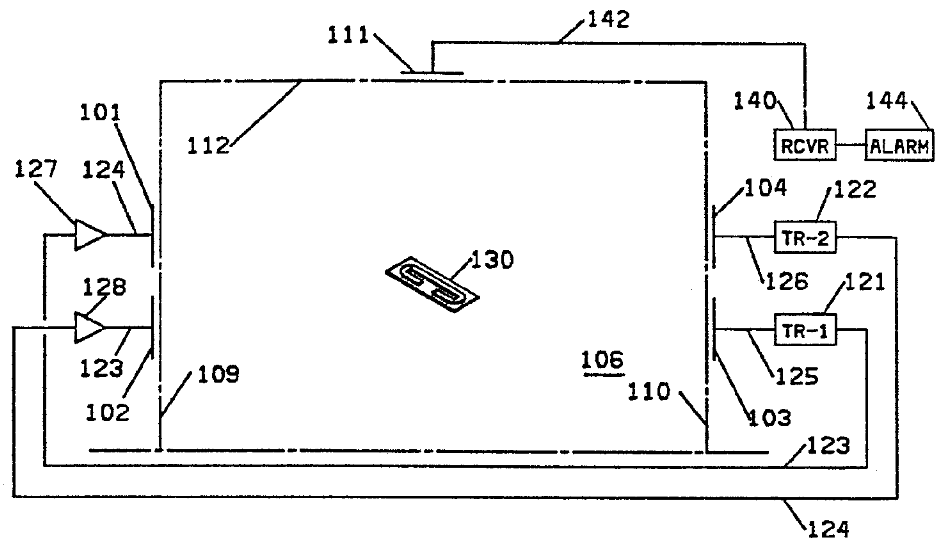

FIG. 6

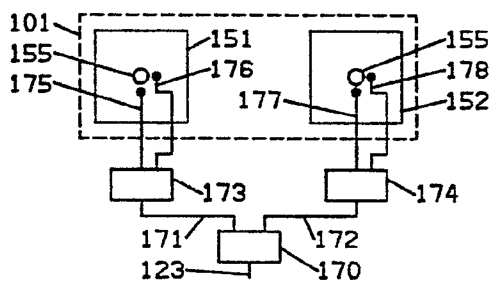

FIG. 12

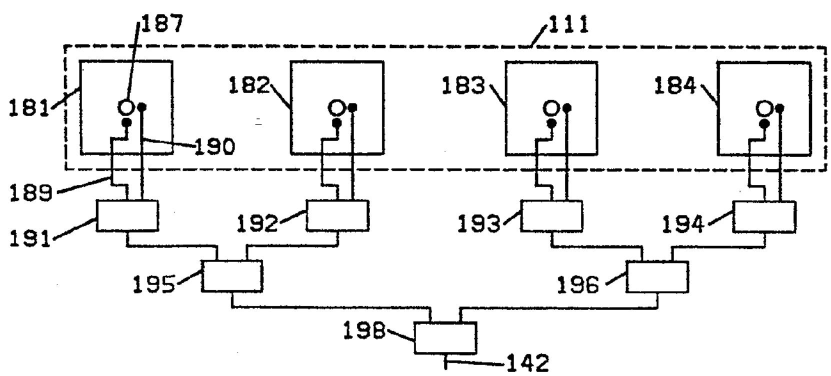

FIG. 13

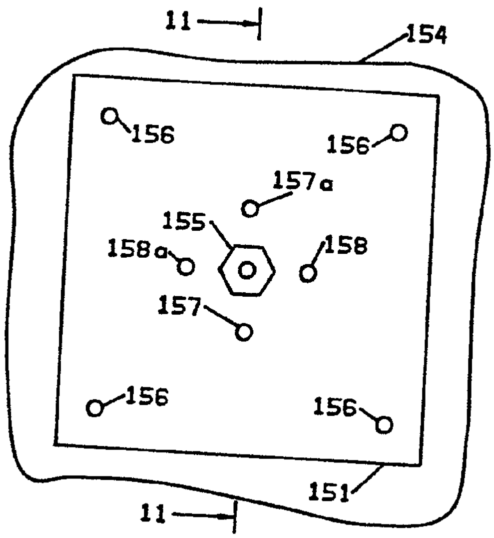

FIG. 10

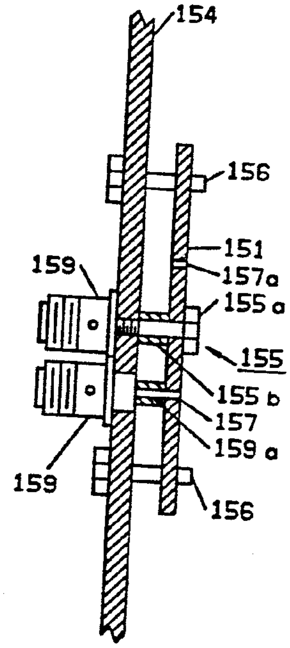

FIG. 11

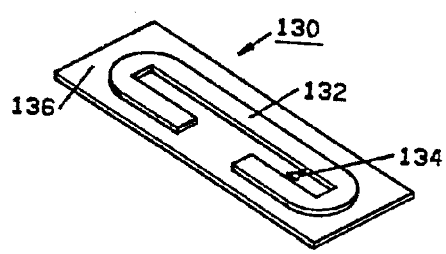

FIG. 7

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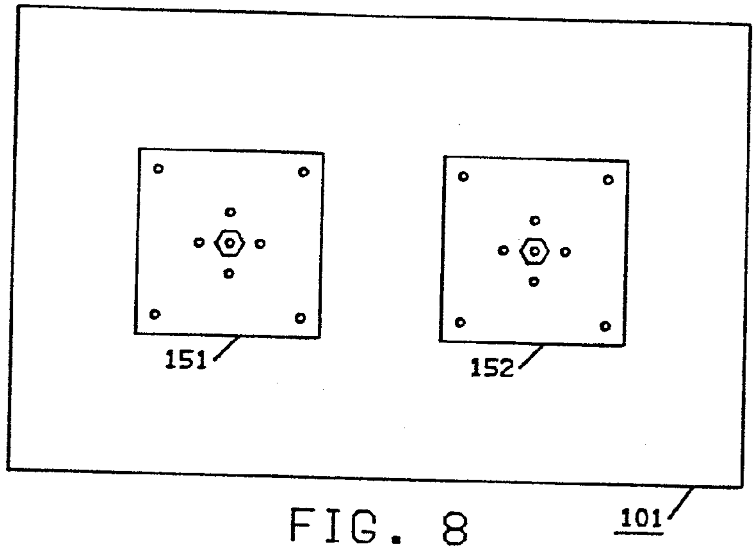

FIG. 8

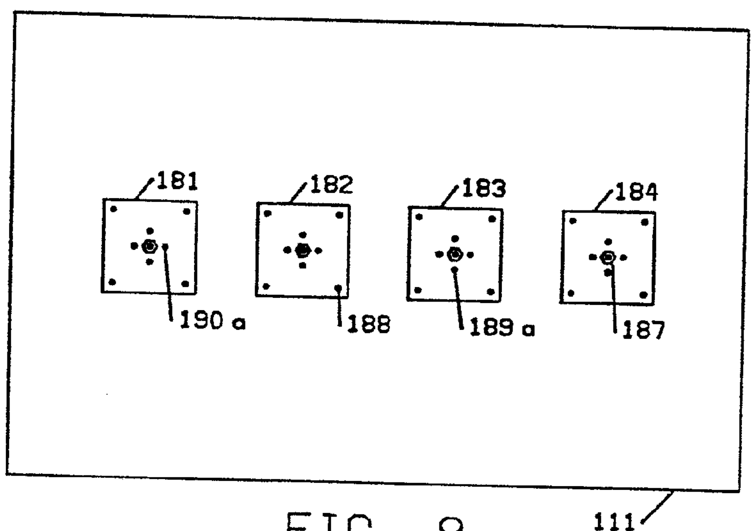

FIG. 9

European Patent Office

EUROPEAN SEARCH REPORT

0105049 Application number

EP 84 10 8629

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y,D	US-A-3 895 368 (GORDON) * Abstract; column 5, lines 23-51; figure 4 *	1	G 08 B 13/24

Y	US-A-3 680 136 (COLLINGS) * Column 2, line 30 - column 3, line 42; figures 1-4 *	1	
A		2-10	

A	US-A-4 386 357 (PATTON) * Column 2, lines 3-49; figures 1,2 *	1-5	
	---		TECHNICAL FIELDS SEARCHED (Int. Cl.4)
A,D	US-A-4 063 229 (WELSH) * Abstract; column 6, line 9 - column 7, line 4 *	1	G 08 B H 01 Q

A,D	US-A-4 366 484 (WEISS) * Abstract *	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	15-11-1984	SGURA S.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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